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Daily provision of instrumental and emotional support to friends is associated with diurnal cortisol during adolescence

Emma Armstrong-Carter[1] | Eva H. Telzer[2]

[1]Department of Education, Stanford University, Stanford, CA, USA

[2]Department of Psychology & Neuroscience, University of North Carolina at Chapel Hill, Chapel Hill, NC, USA

Correspondence
Emma Armstrong-Carter, Stanford University Graduate School of Education, 520 Galvez Mall, Stanford, CA 94305, USA.
Email: emmaac@stanford.edu

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Abstract

This study investigates how adolescents' daily prosocial behaviors to friends are related to diurnal cortisol using between- and within-subject analyses. Further, we examine whether role fulfillment (i.e., feeling like a good friend) moderates links between prosocial behaviors and cortisol. Ethnically diverse adolescents (N = 370; ages 11–18) reported whether they provided instrumental and emotional support to friends for 5 days, and provided four saliva samples/day for 4 days. On the daily level, providing emotional support predicted lower cortisol awakening response the next day, and providing instrumental assistance to friends was associated with a flatter cortisol slope the same day (a cardiovascular risk factor). Adolescents also provided more emotional support on days they had lower CAR and steeper cortisol slopes. On the average level, providing more instrumental support was associated with steeper cortisol slopes among adolescents who felt high levels of role fulfillment, but not among adolescents who felt low levels of role fulfillment. Providing instrumental support may be physiologically taxing from day to day but, across the long term, linked to lower cardiovascular risk for adolescents who experience helping as highly fulfilling.

1 | INTRODUCTION

Adolescents' capacity to engage positively and contribute to the lives of friends is a universal developmental goal, and an important predictor of their physical and emotional well-being (Eisenberg et al., 2015). A robust literature demonstrates that adolescents' social functioning with peers is associated with activity of the hypothalamic–pituitary–adrenal axis (HPAA). The HPAA is an important biological mechanism linking psychosocial stress to physical health that can be indexed via levels of the hormone cortisol (McEwen, 1998). However, prior research has largely focused on challenging or negative peer experiences directed towards youth (e.g., bullying, victimization), rather than behaviors that youth engage in towards others (Murray-Close, 2013a; 2013b). Prior work has also focused on cortisol reactivity in response to laboratory stressors, rather than naturally occurring variation in diurnal cortisol levels within subjects across days (Murray-Close, 2013a; 2013b). Grounded in a positive youth development framework (Lerner et al., 2009), this study examined how adolescents' daily prosocial behaviors towards friends—i.e., the provision of instrumental and emotional support to friends—are associated with diurnal cortisol within and across days, and whether these associations vary by adolescents' experiences of role fulfillment (i.e., feeling like a good friend/person).

1.1 | Prosocial behavior to friends: Instrumental and emotional support

Adolescents' prosocial engagement with peers and friends is an important component of their physical, mental and emotional well-being (Eisenberg et al., 2015). For example, youth who display high levels of prosocial behavior towards their friends—such as sharing and cooperating—exhibit more positive social and emotional outcomes (Caprara et al., 2012; Carlo et al., 2018; Wentzel, 2014). Helping others is also positively associated with physical health benefits, including longevity and cardiovascular health later in adulthood (Brown et al., 2003).

Prosocial behavior can be separated into instrumental assistance (i.e., helping with tangible tasks, lending an item) and emotional support (i.e., listening or providing advice; Tsai et al., 2016). Emotional support involves adolescents' awareness and response to their friends' challenges or worries (Tsai et al., 2016), and may impact adolescents' own well-being in ways that are not apparent by their provision of instrumental assistance (Tsai et al., 2016). For example, one study found that providing instrumental support to a close friend, but not emotional support, was associated with greater emotional well-being during older adolescence (Armstrong-Carter et al., 2020). This work suggests that providing instrumental and emotional support to friends should be examined separately, because they may each have unique associations with adolescents' outcomes.

1.2 | HPAA activity

The HPAA is an important physiological mechanism linking daily social experiences and physical health (McEwen, 1998) and can be indexed in saliva via levels of the hormone cortisol. Cortisol regulates essential bodily functions, including the metabolic, cardiovascular, and immune systems (Chida & Steptoe, 2009). Cortisol levels fluctuate naturally throughout the day, typically peaking 30–45 min after waking in the morning, and declining from morning to evening (Gunnar et al., 2015; Stalder et al., 2016). Despite this normative pattern, individuals vary in their daily cortisol rhythms, and social experiences throughout the day impact cortisol release and fluctuations (Adam et al., 2017). As such, researchers commonly examine how social experiences are linked to three standard markers of HPA axis activity *Cortisol Awakening Response* (CAR; the rise in cortisol shortly after awakening), *Diurnal Cortisol Slope* (the decline in cortisol across the day), and *Area Under the Curve* (AUC; total cortisol output throughout the day). Relatively lower values of AUC and diurnal cortisol slope (i.e., more negative slope) are considered optimal for physical and mental health (Chida & Steptoe, 2009). For CAR, moderate to low levels are considered optimal, whereas levels that are too low are associated with fatigue, burnout, and depression (Boggero et al., 2017). As such, moderate CAR is necessary for the body to mobilize energy to meet the anticipated demands of the upcoming day (Boggero et al., 2017). Since CAR occurs shortly after waking and before the events of the day, it is impacted largely by events the previous day, and thus is commonly and most effectively examined the day following events or experiences of interest (Adam, 2006; Armstrong-Carter et al., 2020; Chida & Steptoe, 2009; Stalder et al., 2016). Thus, CAR reflects both an anticipatory stress response based on anticipated demands of the upcoming day and life events that occurred the previous day.

1.3 | Prosocial behavior and the HPAA

A growing body of cross-sectional and longitudinal research has illustrated that adolescents' social experiences are associated with their cortisol functioning (Prinstein et al., 2020). For instance, youth who experience peer victimization on average exhibit blunted diurnal cortisol levels, including flattened cortisol awakening response (Jiang et al., 2018; Knack et al., 2011), flattened diurnal slopes (Jiang et al., 2018), and lower levels of raw diurnal cortisol values measured at six time points throughout the day (Vaillancourt et al., 2008). However, this research has largely focused on challenging or negative peer interactions, such as victimization and bullying (Murray-Close, 2013a; 2013b). Relatively less work has investigated how adolescents' positive (i.e., prosocial) behaviors relate to cortisol functioning (Murray-Close, 2013a; 2013b). In two cross-sectional studies, 10- to 12-year-old children who exhibited more prosocial behaviors towards friends—as assessed by a combination of peer and parent reports reflecting both instrumental and emotional support—exhibited higher raw levels of afternoon cortisol measured on one day (Oberle, 2018) and across four days (Catherine et al., 2012). In one longitudinal study of maltreated and non-maltreated young children, higher levels of prosocial behavior (as indexed by observer report of behaviors that were considerate, thoughtful, helpful, and cooperative) were related to higher morning cortisol levels one year later, although prosocial behavior was unrelated to afternoon cortisol levels (Alink et al., 2012).

1.4 | Between- versus within-person associations linking prosocial behavior and cortisol

Associations between prosocial behavior and cortisol can be investigated on two timeframes or "levels", both of which are meaningful and important. First, between-person analyses indicate whether adolescents who engage in more prosocial behavior on average across time also exhibit particular cortisol profiles on average. This approach has been the focus of research to date (Prinstein & Giletta, 2020) and yields important information about trait characteristics and long-term associations. Second, it is also important to understand *within*-person associations between prosocial behavior and cortisol, which compare an individuals' behavior and cortisol levels on *one* day to *another* day (Adam, 2006). Comparing days *within* individual participants provides additional insight by holding constant extraneous characteristics of the adolescent, and by revealing how behaviors and cortisol co-occur and fluctuate within short periods of time, such as one day or two days.

Building on between-person, cross-sectional studies, a few daily diary studies have revealed within-person associations between prosocial behavior and diurnal cortisol functioning during adolescence (e.g., Chiang et al., 2016). This work has largely focused on prosocial behavior in the home. For instance, helping the family with instrumental tasks and emotional support was associated with lower cortisol awakening response the next day (Armstrong-Carter, Ivory, et al., 2020; Doane et al., 2018) and flatter diurnal slopes the next day (Doane et al., 2018). In a small sample of older adolescents, daily positive social connection with peers was associated with a greater cortisol awakening response

the next day, although the authors did not measure prosocial behavior explicitly (Sladek & Doane, 2015). Drawing on evidence from the family context, this research suggests that daily prosocial behaviors towards friends may be associated with daily fluctuations in diurnal cortisol within adolescents. Providing instrumental and emotional support to friends may influence diurnal cortisol functioning by impacting social stress levels, increasing feelings of connection with others, or increasing feelings of reward and happiness (Brown & Brown, 2006), which in turn impact physiological arousal and HPAA activity.

Longitudinal data collected via daily diaries offer a unique advantage: they can differentiate and highlight *both* between- and within-person associations (Hoffman & Stawski, 2009). Specifically, although daily diaries are often designed to assess within-person associations, they can also shed light on cross-sectional, between-person associations represented by average levels of a variable across the entire period in which the diaries were collected (e.g., two weeks; Hoffman & Stawski, 2009). For instance, researchers can investigate how prosocial behavior and cortisol co-occur within an individual, in addition to how individual differences in overall levels of prosocial behavior relate to overall levels of cortisol. However, to our knowledge, this has not yet been empirically tested.

1.5 | Individual differences in role fulfillment

According to the positive youth development framework (Lerner et al., 2009) and social identity theory (Tajfel & Turner, 1979), engaging in prosocial behavior—such as providing instrumental and emotional support to friends—is most meaningful when adolescents derive from it a strong sense of purpose and role fulfillment (i.e., feel like a "good person"). This theory suggests that individual differences in role fulfillment may moderate how prosocial behavior relates to adolescents' outcomes.

Emperical research supports the hypothesis that role fulfillment may serve as a protective factor for physiological health. One study of adult women showed that deriving a sense of meaning and purpose about a difficult life experience attenuated the detrimental effects on immune system functioning (Bower et al., 2003). Another longitudinal study of adolescents found that feeling a greater sense of role fulfillment from providing instrumental support to the family buffered increases in inflammation (Fuligni et al., 2009). This work suggests that helping others might similarly moderate the link between prosocial behavior to friends and diurnal cortisol functioning. Specifically, helping friends might protect adolescents against dysregulated cortisol functioning when helping feels rewarding and fulfilling, but not when helping is stressful or physiologically taxing. Moreover, helping friends might be associated with physiological *benefits* (e.g., steeper diurnal cortisol slope) when helping feels fulfilling. Investigating this possibility may shed further light on the social contexts and physiological processes for which role fulfillment is protective.

1.6 | Current study

The current study had two objectives: (1) To understand how adolescents' provision of instrumental and emotional support to peers is associated with diurnal cortisol on the daily level (i.e., within subjects) and average level (i.e., between-subjects). This approach is particularly advantageous for cortisol data, as it helps to isolate between-person versus within-person differences that exist because each individual has their own unique, typical cortisol levels and patterns. We used three standardized cortisol indices: *Cortisol Awakening Response (CAR)*, *Area Under the Curve (AUC)*, and *Diurnal Slope*. We hypothesized that providing instrumental and emotional support to friends would be associated with lower CAR and flatter diurnal slopes, and would not be directly related to AUC, given that providing instrumental and emotional support to family has been linked to lower CAR and flatter diurnal slopes on the daily level (Armstrong-Carter, Ivory, et al., 2020; Doane et al., 2018). (2) To investigate individual differences in these associations by adolescents' feelings of role fulfillment (i.e., feeling like a good friend/person). We hypothesized that helping friends would be associated with lower levels of AUC, and cortisol slope (i.e., possibly reflecting lower cardiovascular risk) when adolescents felt a strong sense of role fulfillment from helping friends, but associated with higher levels of AUC and cortisol slope (i.e., greater cardiovascular risk) when adolescents did not feel a strong sense of role fulfillment. This hypothesis was informed by evidence that role fulfillment buffers the association between helping the family and higher levels of inflammation (Fuligni et al., 2009). We did not have a strong hypothesis whether role fulfillment would moderate the link between helping friends and CAR, given that moderate levels of CAR are ideal and both lower and higher CAR are associated with mental and physical risk (Stalder et al., 2016). To follow up and provide further evidence of directionality of effects, we conducted additional models that examined whether diurnal cortisol markers predicted prosocial behaviors to friends the next day.

2 | METHODS

2.1 | Sample and procedure

Participants included 370 adolescents (57.3% female; M_{age} = 14.63 years, *SD* = 1.39 years; Range 11–18;). The sample was racially diverse: 39.46% were Non-Latinx White (*N* = 146), 25.4% Asian (*N* = 94), 17.8% Latinx (*N* = 66), 10.8% African American (*N* = 40), and 6.5% other race (*N* = 24). Approximately 10% of mothers had less than an eighth-grade education, 13% did not complete high school, 24% completed high school, 27% completed postsecondary education, and 23% completed graduate school (3% declined to answer). Participants were recruited from the community using convenience sampling (e.g., posting flyers at schools and on listservs). Participants were compensated $10 in total for completing daily diaries and $10 for completing saliva

samples, and received a $20 bonus if inspection of the data indicated that they had completed all the diaries and saliva samples correctly and on time.

Participants were provided with diary checklists. In the full project, most participants (80%) were provided 14 days of diaries, whereas 22% of participants (*N* = 83) were only provided with 7 days of diaries. Participants also provided a saliva collection kit to complete on Days 2 through 5. In the study, our analyses only include days 1–6, for which all participants had data, which include the days during which cortisol was collected (days 2–5), as well as the day before and after (in models that include previous day or next day variables). The maximum number of days used in any statistical model in this study is 5.

Most participants (90.43%) completed all days of their dairies across the 6 days used for analysis (*M* = 97.65% of days, *SD* = 35.19% of days, Range = 25%–100%). There were 1,710 total person-day (i.e., Level 1) observations. Diaries included both weekdays and weekends. The order of days differed between participants depending on the day of the week that they started, but all participants had the same proportion of weekday to weekend data if they completed all of the diaries. Participants were instructed to complete their diary in the evening before bedtime. Participants chose to complete the diaries either on paper (63.20%) or via a secure website (36.80%). Participants who responded with paper and pencil were given 14 manila envelopes and an electronic time stamper (Dymo Corporation, Stamford, CT), which verified the time that checklists were completed. The time stamper is a small device that imprints the current date and time and is programmed with a security code so that the correct date and time cannot be changed. Participants were instructed to place their completed checklists into a sealed envelope each night and to stamp the seal of the envelope with the time stamper. Participants who completed surveys online were sent an email with the link to each daily diary survey, and the time and date of completion were recorded via the website. The daily diary checklists were three pages long and each took approximately 5–10 min to complete.

2.2 | Measures

2.2.1 | Prosocial behavior to friends

Participants indicated via diary checklists whether they had engaged in different prosocial behaviors towards friends each day. *Instrumental Assistance to Friends* was the mean of three items each day: lent a friend an item or money (e.g., clothes, car), helped a friend with schoolwork, helped a friend do chores/errands (e.g., laundry, shopping), *M* = 0.17, *SD* = 0.23, Range 0–1. *Emotional Support to Friends* was indexed via a single dichotomous item: provided emotional support to a friend (i.e., listened, advised, comforted) *M* = 0.35, *SD* = 0.48, Range 0–1. Both variables were missing 16.02% of days. At the daily level, we took the average of the item(s) for each type of assistance each day, and the person-mean level of instrumental and emotional support was calculated as the average across all days.

2.2.2 | Diurnal cortisol

Participants provided saliva at four time points each of 4 days, for a total of 16 samples: (a) immediately upon waking up, (b) 30 min after waking up, (c) 5 p.m. (or before dinner), and (d) 8 p.m. (or before bed). Participants were instructed to take their samples before or >30 min after brushing teeth, drinking, eating, or using tobacco. In addition, raw cortisol values exceeding 60 nmol/L were flagged as outliers and excluded from analyses.

Participants recorded the timing of each sample using a log-card and stamped with the electronic time stamper, which printed the current, unalterable, date and time. Participants stamped the card beside the heading for each sample and immediately placed the sample in their fridge. At the end of the saliva collection days, the samples were transferred to the research laboratory and stored in a −80°C freezer. At the end of the data collection period, the samples were shipped to the Laboratory of Biological Psychology at the Technical University of Dresden, Germany where they were assayed using high-sensitivity chemiluminescence-immunoassays (IBL International, Hamburg, Germany). The inter-assay coefficient of variation was <8%.

We computed diurnal slope, CAR, and AUC using standard formulas (see Armstrong-Carter, Ivory, et al., 2020 for more details). *Diurnal slope* represents the decrease in secreted cortisol from morning to evening (*M* = −1.27, *SD* = 1.04, Range −14.84–4.74, missing 13.19% days). We computed diurnal slopes as the difference between the fourth (bedtime) cortisol sample and the first morning sample, divided by the time elapsed between these two samples (Pruessner, Hellhammer, et al., 2003). A relatively healthy diurnal slope is typically a steep, negative decline, whereas a flatter (i.e., less negative) slope is associated with greater stress and cardiovascular risk (Adam et al., 2017).

Area under the curve (AUC) reflects the total daily cortisol output (Pruessner, Kirschbaum, et al., 2003) and is positively associated with chronic stress (Pruessner, Kirschbaum, et al., 2003), *M* = 160.18, *SD* = 88.14, Range −420.08–563.97, missing 16.78% days. We computed AUC using the trapezoid method from the first, third, and fourth cortisol measures (i.e., excluding the second sample, Pruessner, Kirschbaum, et al., 2003).

Cortisol Awakening Response (CAR) is the steep increase in cortisol from wake-up to 30–45 min after awakening (Stalder et al., 2016), which mobilizes bodily energy for the demands of the upcoming day (Fries et al., 2009), *M* = 4.52, *SD* = 13.60, Range −56.42 – 62.95, missing 7.28% days. We computed CAR as the increase in cortisol from wake to 30 min post-wake (Fries et al., 2009). This was a subtraction method. For samples 1 and 2, which were used to compute CAR, 15–45 min between the two samples was considered to be on time (Adam & Kumari, 2009). According to this metric, 98% of samples were collected on time. Seven

samples were collected more than 45 min apart. Four additional samples were not collected in the morning, but upon waking in the afternoon.

2.2.3 | Role fulfillment

Role Fulfillment was calculated from two items in the daily diary in which participants responded on a 7-point Likert-scale ranging from 1 (not at all) to 7 (extremely) to report the extent to which they felt like "a good friend" and "a good person" that day, $M = 5.21$, $SD = 1.42$, Range 0–7, missing 6.48% days. The items were averaged for each day, and the person-mean level of role fulfillment was calculated as the average of the items across all days, overall $\alpha = 0.86$, daily $\alpha = 0.36–0.99$.

2.2.4 | Covariate

We controlled for whether it was a school day or not, because adolescents' cortisol levels have been shown to differ on school days compared to non-school days (Adam et al., 2007). On the daily diaries, adolescents indicated whether they attended school that day or not (1 = school day, 0 = not a school day).

2.2.5 | Demographic characteristics

Mothers reported their education level as an index of family SES, which ranged from 0 (<8th grade completed) to 6 (completed graduate school). Adolescents self-reported their age, gender, and race/ethnicity. For descriptive purposes, race was dummy coded within each race (i.e., Latinx = 1, not Latinx = 0) and categorized into five groups: African American, Asian, Latinx, White, and Other Race.

2.3 | Statistical analyses

Linear mixed effect models nested days (Level 1) within participants (Level 2). We person-centered all Level 1 predictors, and we included on the intercept person-mean values for each of our daily predictors (Curran & Bauer, 2011). Accordingly, in the tables, "Mean-Centered Daily Level Variables" reflect daily level behaviors/cortisol, whereas "Person-Mean Average Level Variables" reflect levels of behaviors/cortisol averaged across days within each individual. To increase the robustness of our findings, we additionally controlled for (1) prior day levels of cortisol indices, to test if helping behaviors were associated with cortisol over and above the previous day, and (2) whether the adolescent attended school that day.

Model 1 tested instrumental and emotional support as simultaneous Level 1 predictors of AUC and diurnal slope the same day, and CAR the next day. Model 2 additionally included daily level and average level interaction terms between each prosocial behavior (i.e., instrumental and emotional support) and role fulfillment. Specifically, we created two daily level interaction terms (i.e., daily levels of instrumental and emotional support multiplied by daily levels of role fulfillment) and two average level interaction terms (i.e., average levels of instrumental and emotional support multiplied by average levels of role fulfillment) and included all four of these interaction terms as predictors in the model. To probe significant interactions, we used the simple slopes technique at 1SD above and below the mean value of the moderator (Aiken et al., 1991). We conducted follow-up models to test for potential bi-directional effects (i.e., cortisol predicting prosocial behavior),

TABLE 1 Correlations between study constructs

	1	2	3	4	5	6	7	8
1. Inst. Support to Friends	1							
2. Emo. Support to Friends	0.53[c]	1						
3. CAR	0.03	0.11[c]	1					
4. AUC	0.15[c]	0.06[c]	−0.09[c]	1				
5. Diurnal Slope	−0.13[c]	0.00	0.29[c]	−0.59[c]	1			
6. Role Fulfillment	0.20[c]	0.28[c]	−0.04[b]	0.00	0.00	1		
7. Gender	0.14[c]	0.25[c]	0.09[c]	0.09[c]	−0.04[a]	0.07[c]	1	
8. Age	0.01	0.08[c]	−0.04[a]	−0.20[c]	0.23[c]	−0.05[b]	0.04[b]	1
9. SES	0.00	0.04[b]	−0.02	0.01	−0.02	−0.05[b]	−0.04[a]	−0.11[c]

Abbreviations: Inst., Instrumental; Emo, Emotional; CAR, Cortisol Awakening Response the next morning; AUC, Area Under the Curve (representing total cortisol output).

[a]$p < .05$.

[b]$p < .01$.

[c]$p < .001$.

as described further below. All analyses were conducted using Stata Software (StataSE, Version 15.1.632).

3 | RESULTS

3.1 | Bivariate correlations

Table 1 displays bivariate correlations using variables averaged across all days. On average, instrumental support to friends was positively correlated with emotional support to friends, role fulfillment, and AUC, and negatively correlated with diurnal slope. Emotional support to friends was positively correlated with role fulfillment, CAR and AUC. Role fulfillment was negatively correlated with CAR.

On average, girls provided instrumental and emotional support to peers more frequently compared to boys, and had higher role fulfillment, CAR and AUC, and lower (i.e., steeper) slopes. Older adolescents provided emotional support to peers more frequently compared to younger adolescents, and had lower role fulfillment, CAR, AUC, and higher (i.e., flatter) slopes. Adolescents from higher SES provided emotional support to peers more frequently compared to adolescents from lower SES and had lower levels of role fulfillment.

3.2 | Daily level associations

3.2.1 | Direct associations

Table 2 displays direct associations linking instrumental and emotional support to cortisol on the daily level (i.e., Mean-Centered Daily Level Variables) and on the average level (i.e., Person-Mean Average Level Variables), controlling for same day levels of each cortisol outcome and whether it was a school day. On the daily level, providing instrumental support to friends was associated with a flatter diurnal slope the same day. Specifically, as displayed in Figure 1, adolescents exhibited a 72.19% decrease in cortisol throughout the day on days they provided more than their average amount of instrumental support, compared to a 74.21% decrease in cortisol throughout the day on days they provided less than their average amount of instrumental support.

In addition, providing emotional support to friends was associated with lower CAR the next day. Specifically, as displayed in Figure 2, adolescents exhibited a 38.11% increase in CAR on days after they provided more than their average amount of emotional support, compared to a 55.38% increase in CAR on days after they provided less than their average amount of emotional support.

3.2.2 | Individual differences by role fulfillment

Table 3 displays how the associations between instrumental and emotional support and cortisol varied by role fulfillment on daily

TABLE 2 Direct daily associations between instrumental and emotional support to friends and cortisol

	CAR	AUC	Slope
	β	*β*	*β*
	(SE)	*(SE)*	*(SE)*
Mean-centered daily level variables			
Instrumental support to friends	−0.27 (0.22)	−0.37[d] (0.21)	0.40[a] (0.19)
Emotional support to friends	−0.24[a] (0.11)	−0.08 (0.10)	0.08 (0.09)
Role fulfillment	−0.06 (0.04)	−0.01 (0.04)	−0.01 (0.04)
Prior day cortisol outcome	0.18[c] (0.04)	−0.00[c] (0.00)	−0.38[c] (0.04)
Person-mean average level variables			
Instrumental support to friends	−0.67[d] (0.35)	0.59 (0.38)	−1.08[b] (0.36)
Emotional support to friends	0.33[a] (0.16)	−0.00 (0.17)	0.40[a] (0.16)
Covariate			
School day	0.08 (0.09)	0.52[c] (0.09)	−0.09 (0.08)
Constant	−0.01 (0.04)	−0.08[d] (0.05)	−0.00 (0.04)

Note.: β represents the standardized coefficient. SE represents the standard error.

Higher values of slope indicate flatter, more positive slopes, whereas lower values of slope indicate steeper, more negative slopes.

Abbreviations: CAR, Cortisol Awakening Response the next morning; AUC, Area Under the Curve (representing total cortisol output).

[a]$p < .05$.

[b]$p < .01$.

[c]$p < .001$.

[d]$p < .10$.

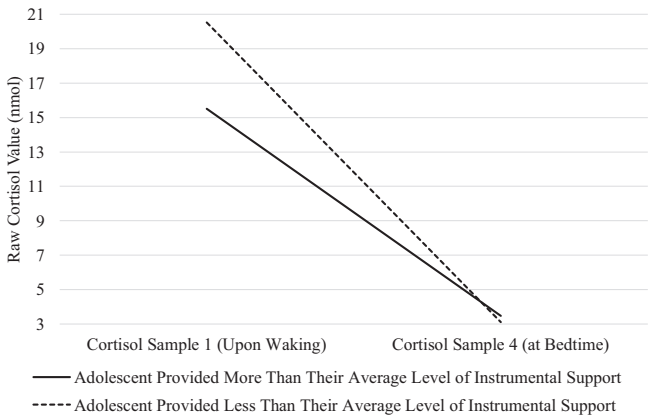

FIGURE 1 Diurnal Cortisol Slope was significantly flatter on days that adolescents provided more than their average level of instrumental support.

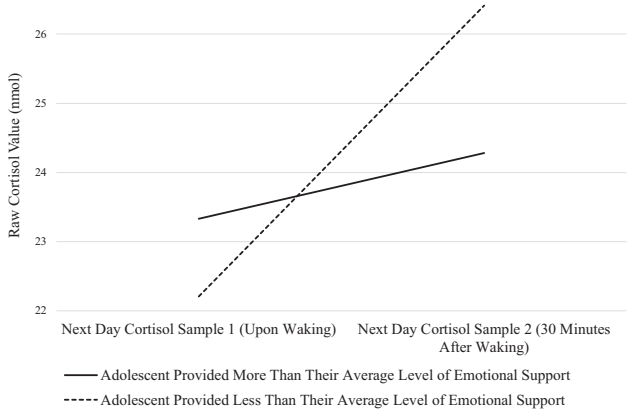

FIGURE 2 Cortisol Awakening Response was significantly lower on days after adolescents provided more than their average level of emotional support.

and average levels. On the daily level, the link between providing support to peers and cortisol outcomes did not vary by role fulfillment.

3.3 | Average level associations

3.3.1 | Direct associations

On the average level, adolescents who provided more frequent emotional support to friends had higher CAR and flatter diurnal slopes on average. In addition, instrumental support was negatively related to diurnal slope, however, this direct association was qualified by a significant interaction with role fulfillment in the subsequent model, so we do not interpret it in this paper. There were no other significant direct associations.

3.3.2 | Individual differences by role fulfillment

On the average level, role fulfillment moderated the association between instrumental support to friends and diurnal slope. As shown in Figure 3, providing instrumental support to friends was associated with a more negative diurnal slope among adolescents with

TABLE 3 Interactive associations: Instrumental and emotional support to friends x role fulfillment predicting cortisol

	CAR		AUC		Slope	
	β	*SE*	*β*	*SE*	*β*	*SE*
Mean-centered daily level variables						
Instrumental support to friends	−0.09	(0.21)	−0.39[d]	(0.21)	0.40[a]	(0.19)
Emotional support to friends	−0.21[a]	(0.11)	−0.07	(0.10)	0.08	(0.09)
Role fulfillment	−0.05	(0.04)	−0.01	(0.04)	−0.01	(0.04)
Previous day cortisol outcome	−0.02[c]	(0.00)	−0.00[c]	(0.00)	−0.38[c]	(0.05)
Daily-level interactions						
Inst X role fulfillment	0.24	(0.23)	0.25	(0.22)	−0.05	(0.20)
Emo X role fulfillment	−0.04	(0.12)	−0.06	(0.11)	0.10	(0.10)
Person-mean average-level variables						
Instrumental support to friends	1.66	(2.01)	0.09	(2.15)	3.96[a]	(1.97)
Emotional support to friends	−0.76	(1.01)	0.87	(1.03)	−0.76	(0.96)
Role fulfillment	0.00	(0.07)	−0.05	(0.07)	0.08	(0.06)
Average-level interactions						
Inst X role fulfillment	−0.44	(0.35)	0.08	(0.38)	−0.90[b]	(0.35)
Emo X role Fulfillment	0.20	(0.18)	−0.16	(0.18)	0.20	(0.17)
Covariate						
School day	0.21[a]	(0.09)	0.53[c]	(0.09)	−0.09	(0.08)
Constant	−0.03	(0.35)	−0.02	(0.38)	−0.44	(0.35)

Note.: β represents the standardized coefficient. SE represents the standard error.

Higher values of diurnal slope indicate flatter, more positive slopes, whereas lower values of slope indicate steeper, more negative slopes.

Abbreviations: Inst, Instrumental support provided to friends; Emo, Emotional support provided to friends; CAR, Cortisol Awakening Response the next morning; AUC, Area Under the Curve (representing total cortisol output).

[a]$p < .05$.

[b]$p < .01$.

[c]$p < .001$.

[d]$p < .10$.

high levels of role fulfillment (i.e., who felt like a good friend/person on average across days), whereas instrumental support was not associated with diurnal slope among adolescents with low levels of role fulfillment. This result was robust to Bonferroni correction (p = .027). There were no other significant interactions.

3.4 | Sensitivity analyses

We conducted additional sensitivity analysis that controlled for physical activity each day (1 = any physical activity, 0 = no physical activity) and the time that adolescents woke up each morning. All significant results remained significant (ps < 0.046). We then controlled for the amount of time sleeping each night. The direct association between emotional support and CAR remained significant (p = .033), and the interaction between instrumental support and role fulfillment remained significant (p = .014). The direct association between instrumental support and cortisol slope became nonsignificant (p = .315). Time sleeping was not a significant mediator for either outcome (p > .05).

3.5 | Cortisol predicting prosocial behavior

To investigate the possibility of bi-directional effects, we tested models in which each cortisol marker predicted instrumental and emotional support the next day, controlling for levels of instrumental and emotional support the previous day. Specifically, we tested each cortisol marker in a separate model and included both mean-centered and person-mean variables as predictors, consistent with our analysis above. Table 4 displays these results. Adolescents provided more emotional support on days after they had lower CAR and steeper, more negative cortisol slopes than their average. There were no other significant results in these models.

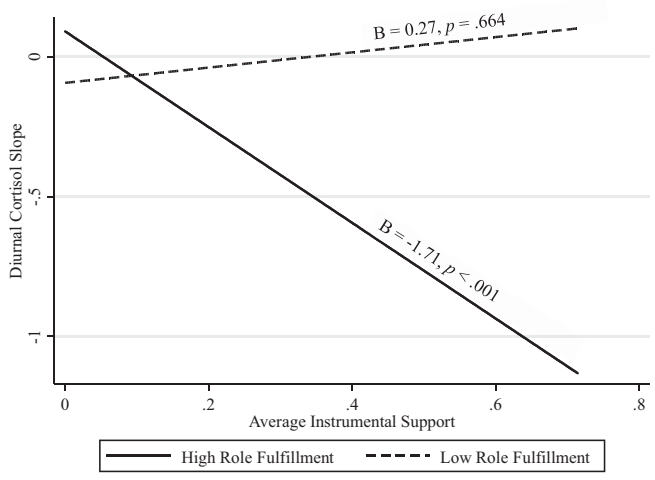

FIGURE 3 Instrumental support, role fulfillment and diurnal cortisol slope.

4 | DISCUSSION

The goal of this study was to understand how adolescents' prosocial behavior to friends relates to their diurnal cortisol within and across days. In a large sample of ethnically and socio-economically diverse adolescents, we investigated how adolescents' daily provision of instrumental and emotional support to friends predicted cortisol awakening response (CAR), diurnal slope, and total cortisol output (AUC). Further, we tested whether role fulfillment (feeling like a good friend/person) moderated the links between prosocial behavior and cortisol. We found that when adolescents listened to or advised their friends more than usual, they exhibited lower CAR the next morning. In addition, on days that adolescents helped their friends with tangible, instrumental tasks more than usual, they displayed flatter diurnal slopes, a marker of cardiovascular risk (Adam et al., 2017). These results were consistent regardless of the amount of fulfillment that adolescents felt each day. However, on average, adolescents who provided more frequent instrumental support to friends and who *also* experienced a strong sense of fulfillment displayed a steeper diurnal slope, a cardiovascular protective factor (Adam et al., 2017). This finding suggests that while providing instrumental support may be physiologically taxing from day to day, across the long term, it is associated with more optimal physiological regulation and lower cardiovascular risk for adolescents who derive a strong sense of fulfillment.

4.1 | Emotional support and cortisol awakening response

We found that when adolescents helped a friend by listening or giving advice (but not when they helped with instrumental tasks) more than their usual amount, they displayed a lower CAR the next morning, controlling for prior day levels of CAR, and whether it was a school day or weekend. Why might emotional support be related to CAR and not total cortisol output (i.e., AUC) or cortisol slope? And why is emotional support, but not instrumental support, linked to cortisol awakening response? Part of the explanation might be that CAR is relatively independent from cortisol output during the rest of the day and is only loosely associated with later diurnal cortisol (Stalder et al., 2016). As such, it may operate on different regulatory mechanisms compared to diurnal slope and AUC (Chida & Steptoe, 2009). A meta-analysis revealed that psychosocial experiences have unique and significant associations with CAR, suggesting that it may be particularly sensitive to psychosocial and emotional processes relative to other cortisol indicators (Chida & Steptoe, 2009). Emotional support may be uniquely linked to CAR because CAR is highly sensitive to socioemotional processes, and providing emotional support uniquely involves awareness and responsiveness to friends' worries or problems, unlike instrumental support. In prior research, adolescents also had lower cortisol awakening response the day after helping their families with instrumental and emotional tasks,

TABLE 4 Bi-directional associations: cortisol indices predicting instrumental and emotional support

	Instrumental support		Emotional support		Instrumental support		Emotional support		Instrumental support		Emotional support	
	β	*SE*	*β*	*SE*	*β*	*SE*	*β*	*SE*	*β*	*SE*	*β*	*SE*
Mean-centered daily level variables												
CAR	−0.00	(0.00)	−0.02[a]	(0.01)								
AUC					0.00	(0.00)	0.00[d]	(0.00)				
Slope									−0.01	(0.01)	−0.29[a]	(0.14)
Previous day outcome	−0.07[d]	(0.04)	−0.80[b]	(0.28)	−0.07	(0.04)	−0.78[b]	(0.28)	−0.08[d]	(0.04)	−0.81[b]	(0.28)
School day	0.09[c]	(0.02)	0.36	(0.22)	0.10[c]	(0.02)	0.14	(0.24)	0.09[c]	(0.02)	0.31	(0.22)
Person-mean average-level variables												
CAR	−0.00	(0.00)	0.03	(0.02)								
AUC					0.00	(0.00)	−0.00	(0.00)				
Slope									−0.02[d]	(0.01)	0.24	(0.24)
Constant	0.15[c]	(0.01)	−1.12[c]	(0.22)	0.13[c]	(0.03)	−0.70	(0.49)	0.10[c]	(0.02)	−0.60	(0.37)

Note.: β represents the standardized coefficient. SE represents the standard error.

Higher values of diurnal slope indicate flatter, more positive slopes, whereas lower values of slope indicate steeper, more negative slopes.

CAR, Cortisol Awakening Response; AUC, Area Under the Curve (representing total cortisol output).

[a]$p < .05$.

[b]$p < .01$.

[c]$p < .001$.

[d]$p < .10$.

as measured by combined metrics that reflected both types of helping (Armstrong-Carter, Ivory, et al., 2020; Doane et al., 2018). Emotional support could partially account for this consistency in findings across peer and family contexts.

Since moderate levels of CAR are associated with optimal physical and mental health, it is unclear whether reductions in CAR the day after providing more than average amounts of emotional support are unhealthy (i.e., blunting to an unhealthy degree) or healthy (i.e., lowering to normative, optimal levels; Chida & Steptoe, 2009). On the one hand, reduced CAR could be beneficial for health. On average in our sample, CARs were slightly higher than in previous community samples of adolescents (e.g., Chiang et al., 2016; Doane et al., 2018; Sladek & Doane, 2015). Although mean levels cannot be definitively compared due to variable measurement error across different laboratories and assays, this suggests that participants in our sample may be experiencing slightly higher levels of stress compared to prior samples. As such, reductions in CAR in our sample may reflect reductions to optimal levels. On the other hand, reduced CAR after providing emotional support might instead reflect unhealthy, blunting of CAR and mental and physical health risk (Stalder et al., 2016). A moderate rise in CAR is necessary to mobilize the body's energy to meet the upcoming demands of the day (Chida & Steptoe, 2009), and blunted CAR has been linked to emotional difficulties including fatigue, burnout, and depression (Boggero et al., 2017), and social difficulties including loneliness (Sladek & Doane, 2015) and peer victimization (Jiang et al., 2018; Knack et al., 2011).

The negative daily association between emotional support and next day CAR is further complicated by our average level results, which showed a *positive* association between emotional support and CAR. Specifically, on average, adolescents who provided more frequent emotional support to friends had higher CAR. This suggests that at the daily level, emotional support is associated with acute decreases in CAR, but across time, more frequent emotional support is linked to an overall increase in CAR. More research is needed to interpret whether increases or decreases in CAR are reflective of optimal functioning or dysregulation. Specifically, future research should clarify whether the changes in CAR observed after providing emotional support is positive or negative by examining how it relates to mental and physical health risk factors (e.g., depression, cardiovascular risk, blood pressure, body mass index), both concurrently and across the lifespan.

4.2 | Emotional support and diurnal cortisol slope

Average level results also demonstrated that adolescents who provided more frequent emotional support to friends had flatter diurnal slopes, a known risk factor for mental and cardiovascular illness (Adam et al., 2017). It is possible that adolescents who provide emotional support routinely across days are frequently serving as primary support or confident for their friend, which could be physiologically taxing, reflected in flatter diurnal slopes. This interpretation is consistent with research on the phenomena of *adultification*, whereby youth who provide ongoing emotional care for another

individual can experience a mental and physical toll themselves (Hooper et al., 2014).

4.3 | Instrumental support is related to flatter diurnal cortisol slope the same day

Our study also found that on days that adolescents helped their friends with instrumental tasks (e.g., school work, lending an item, running an errand), more than their average, they exhibited a flatter diurnal cortisol slope throughout the day. This finding should be interpreted with caution, because it became non-siginficant in sensitivity analysis controlling for amount of sleep the prior night. However, this finding provides suggestive evidence that helping friends with instrumental tasks might be physiologically taxing for adolescents on a day to day basis. In particular, helping friends might be physiologically taxing if it is stressful or interferes with adolescents' other desires or responsibilities—for example, their school work, family time, or other positive interactions with friends that do not involve actively providing instrumental support. Supporting this idea, one study found that providing instrumental support to friends was *not* associated with positive emotions the same day (Morelli et al., 2015). Another study found that although providing instrumental support to friends was linked with positive emotions the same day, it also was simultaneously associated with negative emotions among young men (Armstrong-Carter, Guassi Moreira, et al., 2020). Thus, helping friends with instrumental tasks might be linked to flatter diurnal slopes—a physical health risk factor— if it is experienced as stressful or taxing.

The finding that adolescents have flatter diurnal slopes after helping friends with instrumental tasks is consistent with another diary study of adolescents, which found that helping family was associated with flatter diurnal slopes the next day (Doane et al., 2018). In other cross-sectional analyses, 10-year-olds who exhibited more prosocial behaviors towards friends—as assessed by a combination of peer and parent reports reflecting both instrumental and emotional support—exhibited higher levels of afternoon cortisol measured on one day (Oberle, 2018) and across four days (Catherine et al., 2012). Although the authors did not explicitly calculate diurnal slope, higher afternoon cortisol levels are consistent with a flatter diurnal slope. Another study found that helping the family more on average was linked to higher levels of inflammation, a different cardiovascular risk factor (Fuligni et al., 2009). These findings provide converging evidence that that although helping friends can be emotionally rewarding and beneficial for adolescents, it can also be physiologically taxing from day to day. Consistent with this interpretation is the theory of "skin deep resilience," whereby youth can show positive adaptation on behavioral and emotional measures while simultaneously experiencing risk factors via markers of stress-physiology that predict poor physical health and allostatic load (Hostinar & Miller, 2019). Providing instrumental support may be psychologically rewarding (Armstrong-Carter, Guassi Moreira, et al., 2020), while simultaneously physiologically taxing.

4.4 | Role fulfillment as a moderator

Moderation analyses with role fulfillment revealed that the daily associations described above were robust to daily fluctuations in role fulfillment. In other words, regardless of how fulfilled adolescents felt each day, instrumental support was associated with a blunted cortisol slope the same day, and emotional support was associated with lower CAR the next day.

In contrast to the daily level results, average level results revealed significant differences by levels of role fulfillment. Specifically, adolescents who provided instrumental support to friends more frequently on average across days *and* derived greater role fulfillment from these actions exhibited a steeper pattern of diurnal slope that declined throughout the day, whereas instrumental support to friends was unrelated to cortisol slope for adolescents with low rolefillment on average. Negative, declining diurnal cortisol slope is considered healthier because it reflects a normative rise and fall of cortisol throughout the day, and is related to greater mental and physical well-being concurrently and across the lifespan (Adam et al., 2017). Deriving a strong sense of personal fulfillment from helping friends may be associated with lower cardiovascular risk.

Our finding that instrumental support was linked to positive cortisol functioning (representing lower cardiovascular risk) only among adolescents with high levels of role fulfillment corroborates prior research demonstrating that role fulfillment can be protective. In one prior study, helping the family was on average linked to higher levels of circulating inflammatory markers (a health risk factor), but not when adolescents derived higher family role fulfillment (i.e., felt like a good son/daughter/sibling) from helping (Fuligni et al., 2009). Moreover, adolescents who derive a strong sense of role fulfillment from helping the family showed greater neural activation of reward-related areas of the brain during a task when they chose family over the self, compared to adolescents who did not feel a strong sense of role fulfillment (Telzer et al., 2010). By examining helping behaviors towards friends, our finding extends this prior evidence that role fulfillment buffers the link between helping and physiological outcomes to the social sphere. Studying physiological functioning in the context of social experiences is particularly important during adolescence, a developmental transition when youth are increasingly engaging and valuing positive social interactions outside of the family unit (Dahl et al., 2018).

The finding that helping behavior was more beneficial for adolescents who on average felt higher levels of role fulfillment, but did not vary by role fulfillment on a day to day basis, is intriguing. Role fulfillment derived from helping friends may be protective for adolescents who help more on average, compared to their peers who help less on average. In contrast, role fulfillment does not seem to be protective within individual adolescents, i.e., when comparing days on which individuals experienced role fulfillment to days on which they did

not experience role fulfillment. One reason for this divergence may be that role fulfillment is most protective for adolescents' physiological well-being over the long term, whereas small fluctations in daily role fulfillment are relatively less impactful. Over the course of several days (i.e., 6 days in our study), small, daily feelings of role fulfillment may gradually build up and contribute over time to a deeper, overarching sense of fulfillment that is more robustly protective for physiological health.

4.5 | Physiological antecedents to prosocial behavior

The links between prosocial behavior to friends and HPAA functioning emerged as reciprocal and are likely bi-directional. By investigating bi-directional pathways, we found that adolescents provided more emotional support on days they had lower CAR in the morning and lower (i.e., steeper) slopes throughout the day. Although it is unclear whether lower CAR is optimal or not, relatively steeper cortisol slopes are consistently associated with lower cardiovascular risk and better mental health (Adam et al., 2017; Chida & Steptoe, 2009). Adolescents may be more able to engage positively with peers when they are physiologically more regulated (i.e., exhibiting a typical decline diurnal cortisol slope throughout the day). Physiological regulation may enable adolescents to support their friends by helping them to maintain positive mood, energy, motivation, and awareness of their emotional needs.

Our investigation of bi-directional effects extends prior work by demonstrating that adolescents' physiological regulation may represent a context for promoting behaviors of listening to or advising their friends. In prior research from this sample, adolescents were more likely to help their families with instrumental tasks the day after they had slept more (BLINDED; 2021). Other research that has examined the contexts of prosocial behavior has largely focused on factors outside of the adolescent, such as the needs of the recipient, including parental fatigue (Tsai et al., 2013, 2016). One study found that 6-year-old children with higher baseline cortisol values displayed more empathy toward a distressed, unfamiliar adult during a laboratory paradigm (e.g., asking what happened or offering assistance; Apter-Levi et al., 2016). As others have suggested (Miller, 2018), future longitudinal research would help to clarify the extent to which HPAA activity is a mechanism or a result of prosocial behavior. Future longitudinal studies could also illuminate how the relations between cortisol and prosocial behavior fluctuate across development, from childhood to emerging adulthood (Miller, 2018).

4.6 | Limitations and future directions

We acknowledge several limitations. First, we were unfortunately unable to control for smoking or alcohol use which could impact cortisol (Adam et al., 2017). We were also unable to control completely for medication use as we only collected this information from a subset of participants. Future research should control for these variables. In addition, we calculated CAR from two cortisol samples taken at waking and 30 min after waking; contrasting the more recent recommendation to use two samples taken at 30 and 45 min after waking (Stalder et al., 2016).

Due to the rich nature of our daily diary and cortisol assessments, there was also a level of missing data. In particular, days that adolescents did not respond to the diaries or did not provide cortisol samples might represent the most difficult days. Further, our measures of instrumental and emotional support do not reflect the amount of time spent on each activity, or the variation in different activities beyond the instrument/emotional categorization. Future work should incorporate more detailed measures that capture the amount of time, time of day, and intensity of prosocial behavior. Importantly, future work should also measure the motivations for prosocial behaviors, and examine this as a moderator. Since we found that providing instrumental support divergently related to diurnal cortisol slope depending on adolescents' levels of role fulfillment, motivation for helping friends is likely another key moderator.

4.7 | Conclusions

Positive youth development frameworks underscore the importance of studying adolescents' prosocial contributions to the lives of others (Fuligni, 2018; Lerner et al., 2009). This study extends emerging interest in understanding how adolescents' daily prosocial behavior "gets under the skin" (Fuligni & Telzer, 2013), and is linked to the regulation of stress-physiological systems. Studying stress-physiology indexed via levels of the hormone cortisol provides unique insight to the ways in which adolescents respond to social experiences that are not readily observable or indicated by self-report (Obradović & Armstrong-Carter, 2020), but are meaningfully linked to adolescents' well-being both concurrently and across the lifespan (Adam et al., 2017).

Prior research demonstrates that helping friends is a meaningful and rewarding experience (Armstrong-Carter, Guassi Moreira, et al., 2020; Morelli et al., 2015), but can also be taxing for some youth (Armstrong-Carter, Guassi Moreira, et al., 2020), and associated with biological markers of physical risk, as indexed by heightened raw cortisol levels (Alink et al., 2012; Catherine et al., 2012; Oberle, 2018). Our study extends this work. We demonstrate that providing emotional support is linked to lower cortisol awakening response the next morning, which could either reflect a reduction to healthy levels or a negative blunting. In addition, while providing instrumental support may be physiologically taxing on a day to day basis (reflected in a flatter cortisol slope), across the long term, it is associated with more optimal physiological regulation and lower cardiovascular risk (reflected in a steeper cortisol slope) for adolescents who experience their actions as fulfilling. Bi-directional associations strengthened the interpretation that prosocial behavior reciprocally influences and is influenced by underlying cortisol functioning.

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CONFLICT OF INTEREST

The authors have no conflict of interest to declare.

DATA AVAILABILITY STATEMENT

Data and syntax are available upon request.

ORCID

Emma Armstrong-Carter https://orcid.org/0000-0002-5847-9486

Eva H. Telzer https://orcid.org/0000-0002-2351-6339

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